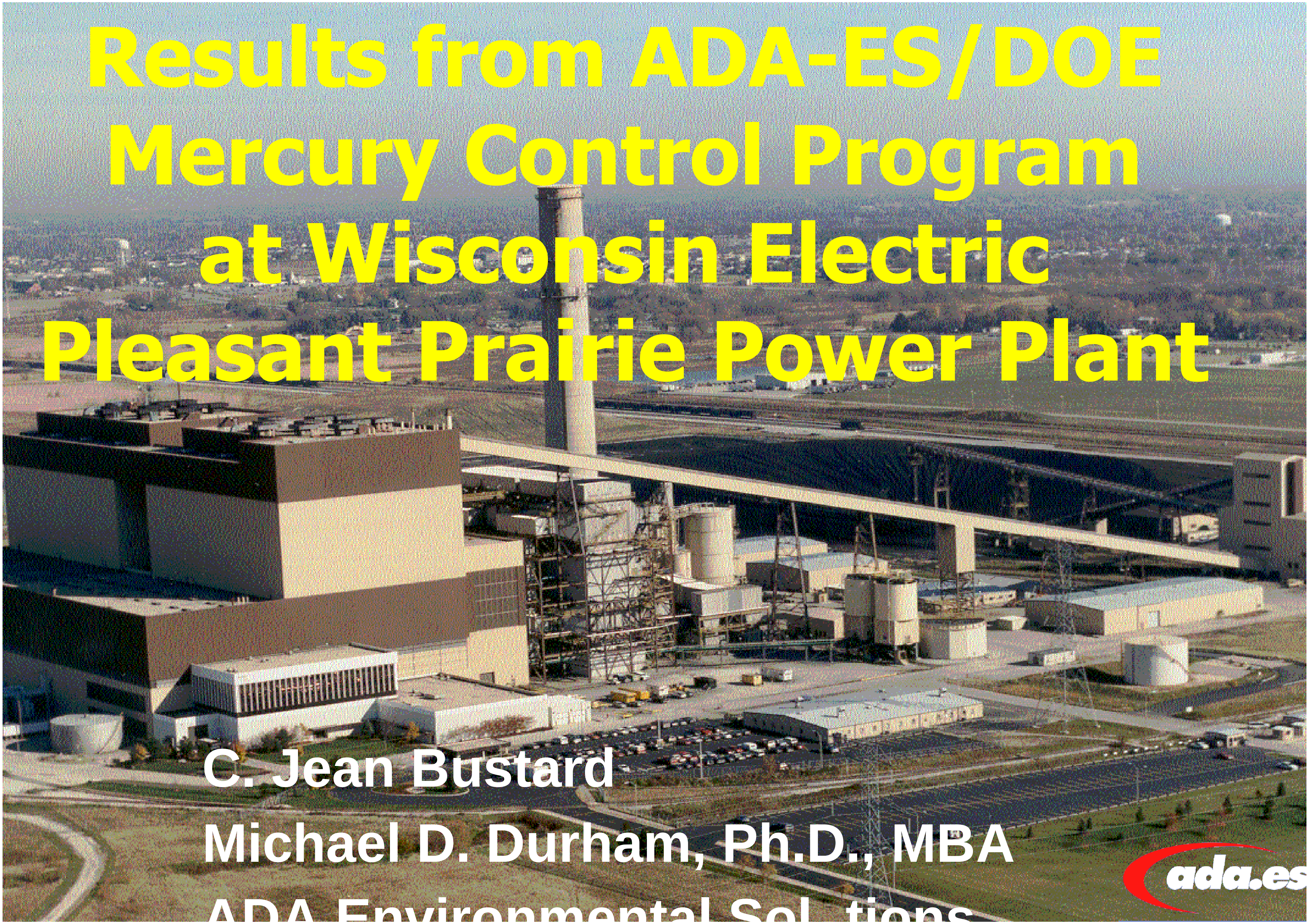


Results from ADA-ES/DOE Mercury Control Program at Wisconsin Electric Pleasant Prairie Power Plant

C. Jean Bustard

Michael D. Durham, Ph.D., MBA

ADA Environmental Solutions

Outline

- Overview of DOE/NETL Program
- Results from Alabama Power Program Using a COHPAC Fabric Filter
- Results from Wisconsin Electric Pleasant Prairie Using an Electrostatic Precipitator
- Conclusions

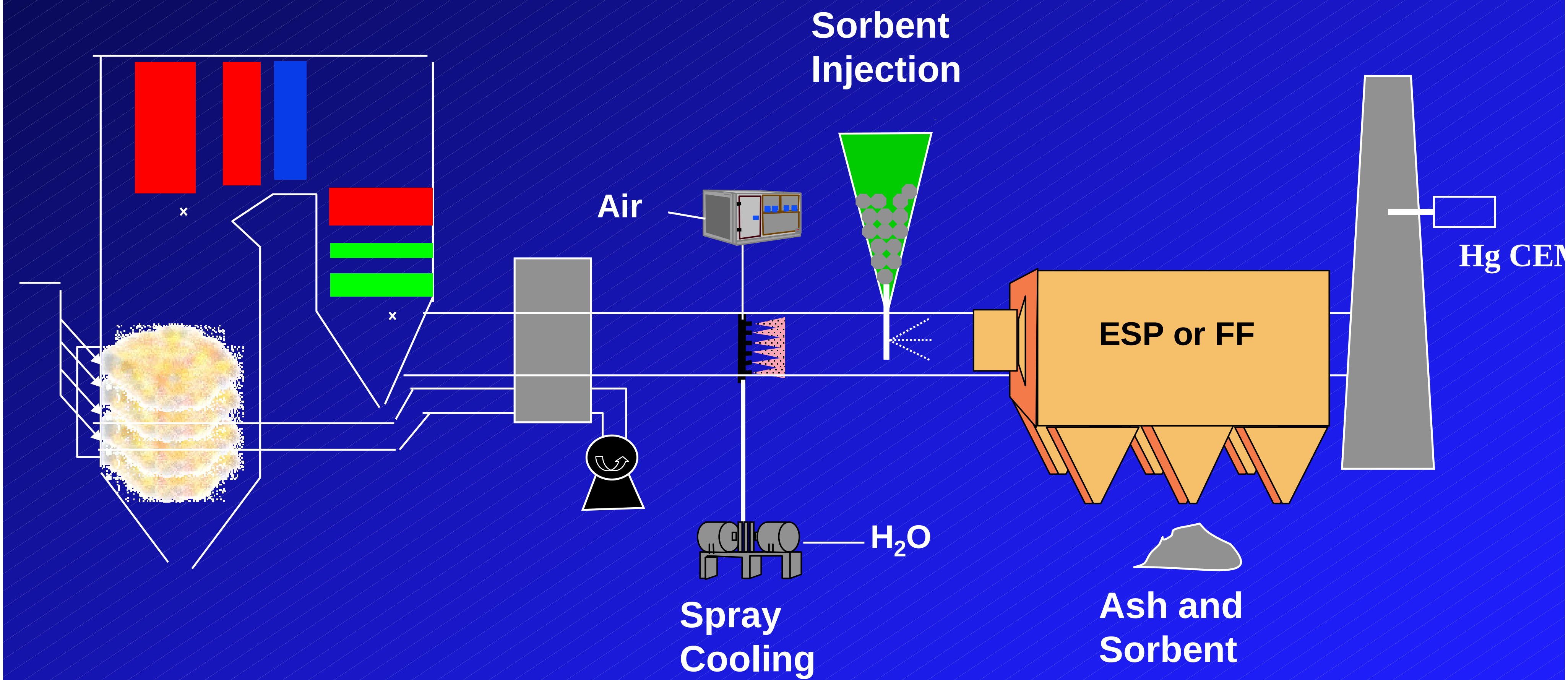
ADA-ES Hg Control Program

- Full-scale field testing of sorbent-based mercury control on non-scrubbed coal-fired boilers
- Primary funding from DOE National Energy Technology Laboratory (NETL)
- Co-funding provided by:
  - Southern Company
  - Wisconsin Electric
  - PG&E NEG
  - EPRI
  - Ontario Power Generation
  - First Energy
  - TVA
  - Kennecott Energy

Project Overview

- Perform first full-scale evaluations of mercury control on coal-fired boilers (up to 150 MW equivalent).
- Evaluate effectiveness of sorbent-based Hg control (activated carbon).
- Test several different power plant configurations.
- Document all costs associated with Hg control.

Coal-Fired Boiler with Sorbent Injection and Spray Cooling



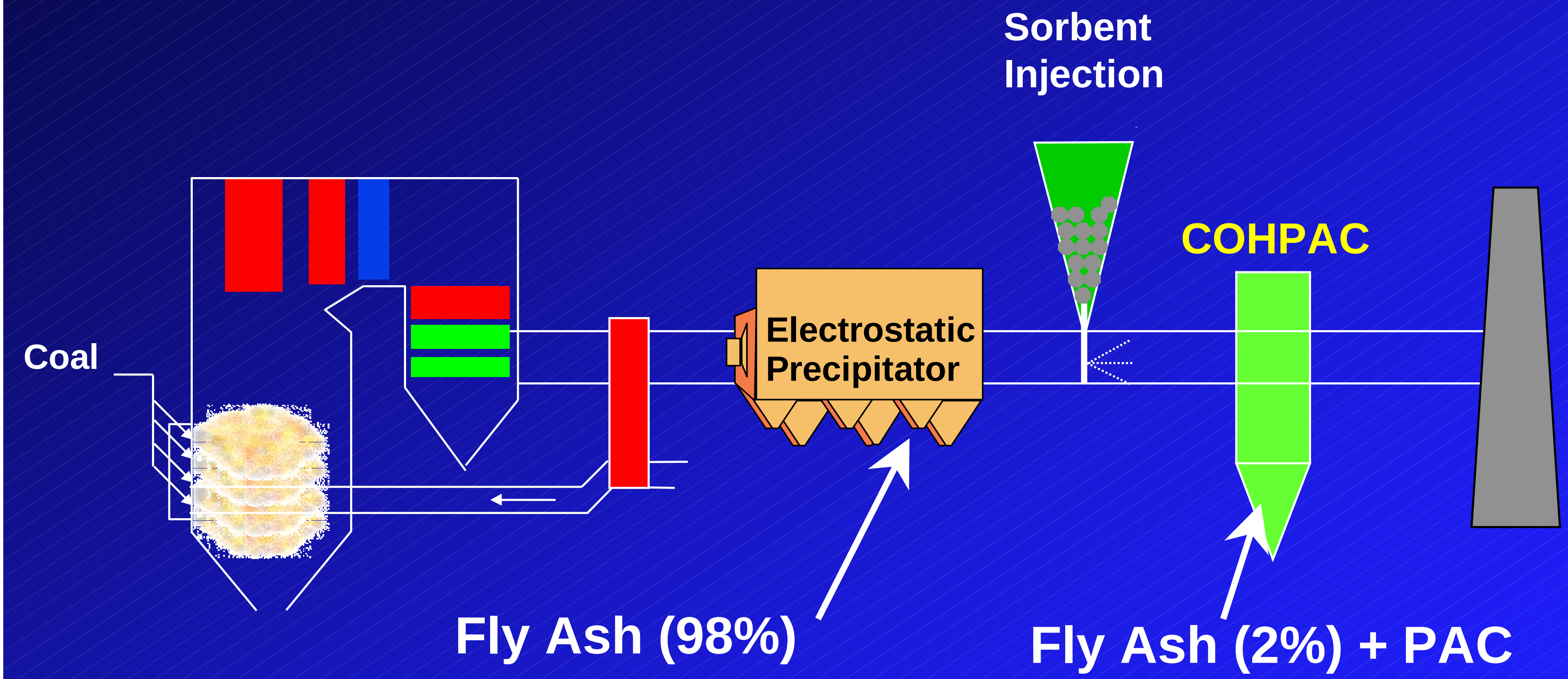
DOE/NETL Test Sites

Test Site	Coal	Particulate Control	Test Dates
Alabama Power Gaston	Bituminous	HS ESP COHPAC FF	Spring 2001
Wisconsin Electric Pleasant Prairie	PRB	Cold Side ESP	Fall 2001
PG&E NEG Brayton Point	Bituminous	Cold Side ESP	Summer 2002
PG&E NEG Salem Harbor	Bituminous	Cold Side ESP	Fall 2002

Alabama Power E.C. Gaston Station

- Alabama Power Company E.C. Gaston Electric Generating Plant Unit 3, Wilsonville, AL
- 270 MW firing a variety of low-sulfur, washed Eastern Bituminous coals
- Particulate Collection System
  - Hot-side ESP, SCA = 274 ft^2/1000 acfm
  - COHPAC baghouse supplied by Hamon Research-Cottrell
- Wet ash disposal to pond

Site Test Configuration with EPRI TOXECON at Alabama Power Plant Gaston



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Advantages of TOXECON

- Majority of fly ash remains acceptable for sale
- Takes advantage of performance of existing ESP
- Reduce requirement for Hg sorbents
- Small footprint for new baghouse

Field Test Measurements

- **Mercury:**
  - S-CEM (Apogee Scientific)
  - Draft Ontario Hydro
- **Monitor effect of sorbent injection on PCD performance**
- **Ash and coal samples**

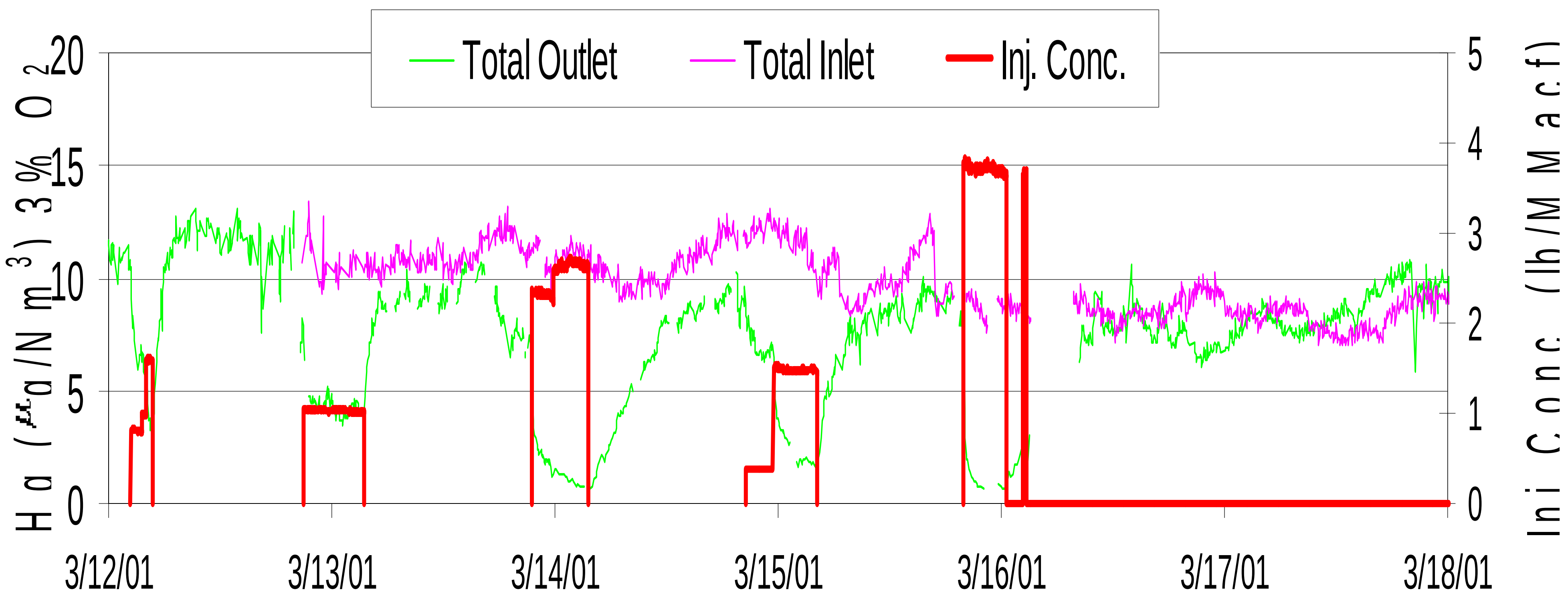
Sorbent Injection Tests

- **Baseline:**
  - **Ontario Hydro Measurements**
- **Parametric tests:**
  - **Three weeks of parametric testing of different sorbents, operating conditions, injection concentrations**
- **Long-term tests:**
  - **Two weeks of operation at optimum conditions**
  - **Ontario Hydro Measurements**

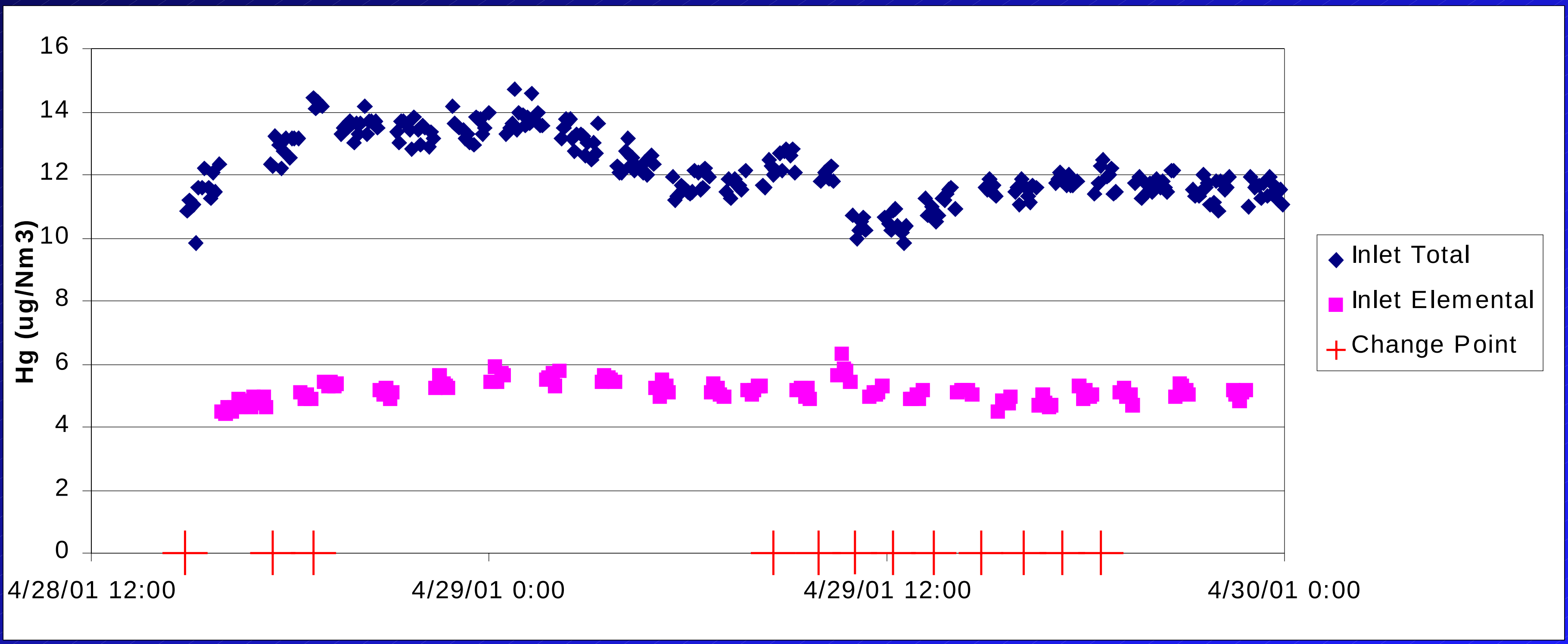
Carbons Used in Parametric Tests

CARBON DESCRIPTION	COMMENTS
Norit FGD (18 microns)	Benchmark sorbent Lignite based
Ground FGD (14 microns)	Effect of smaller size
FGL (18 microns)	Effect of lower capacity (lower cost)
HydroDarcoC (30 microns)	Effect of coarser size
PAC2B (18 microns)	Subbit/bit blend
Insul (7 microns)	Effect of smaller size Acid washed

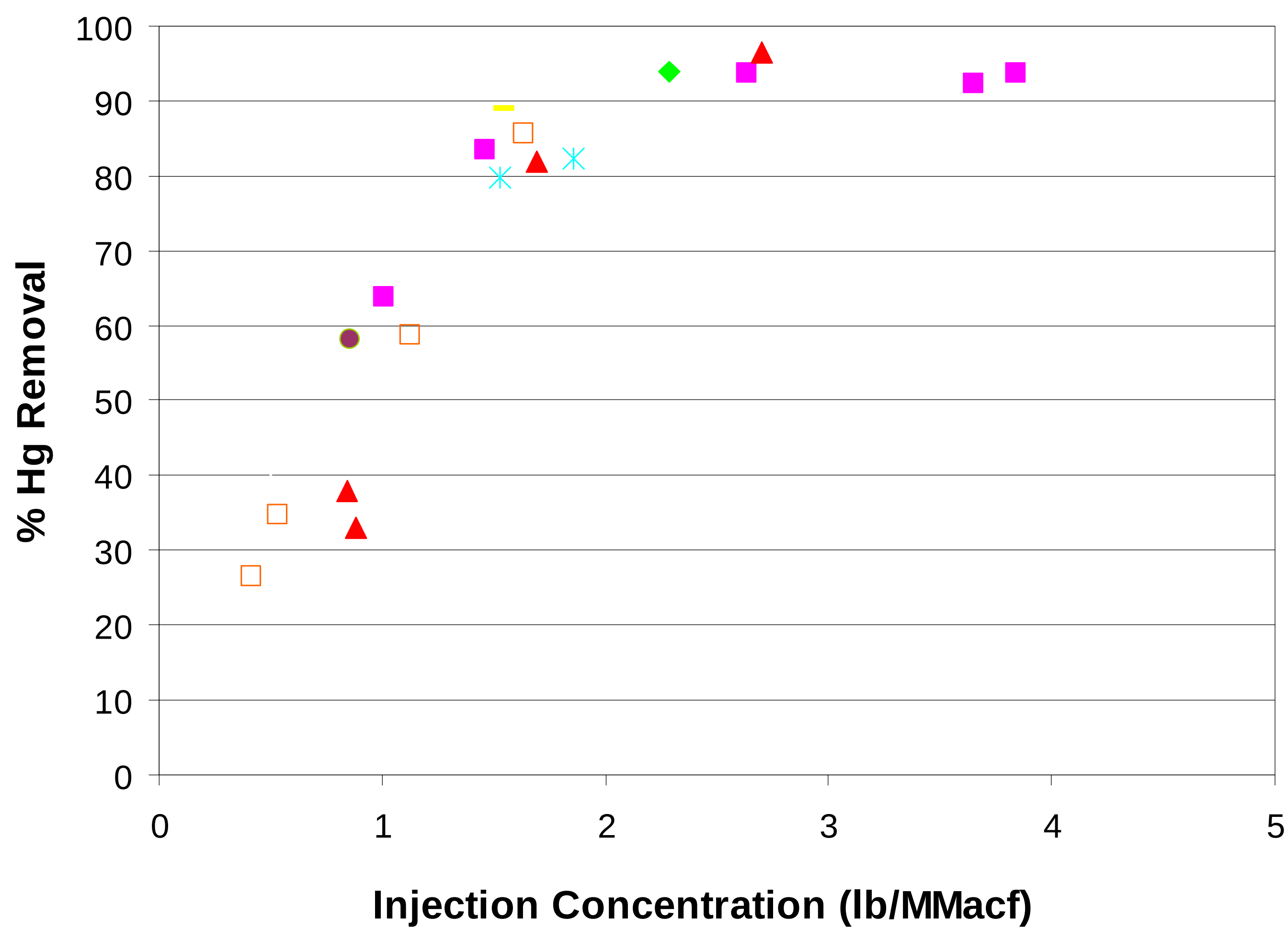
Example of S-CEM Data



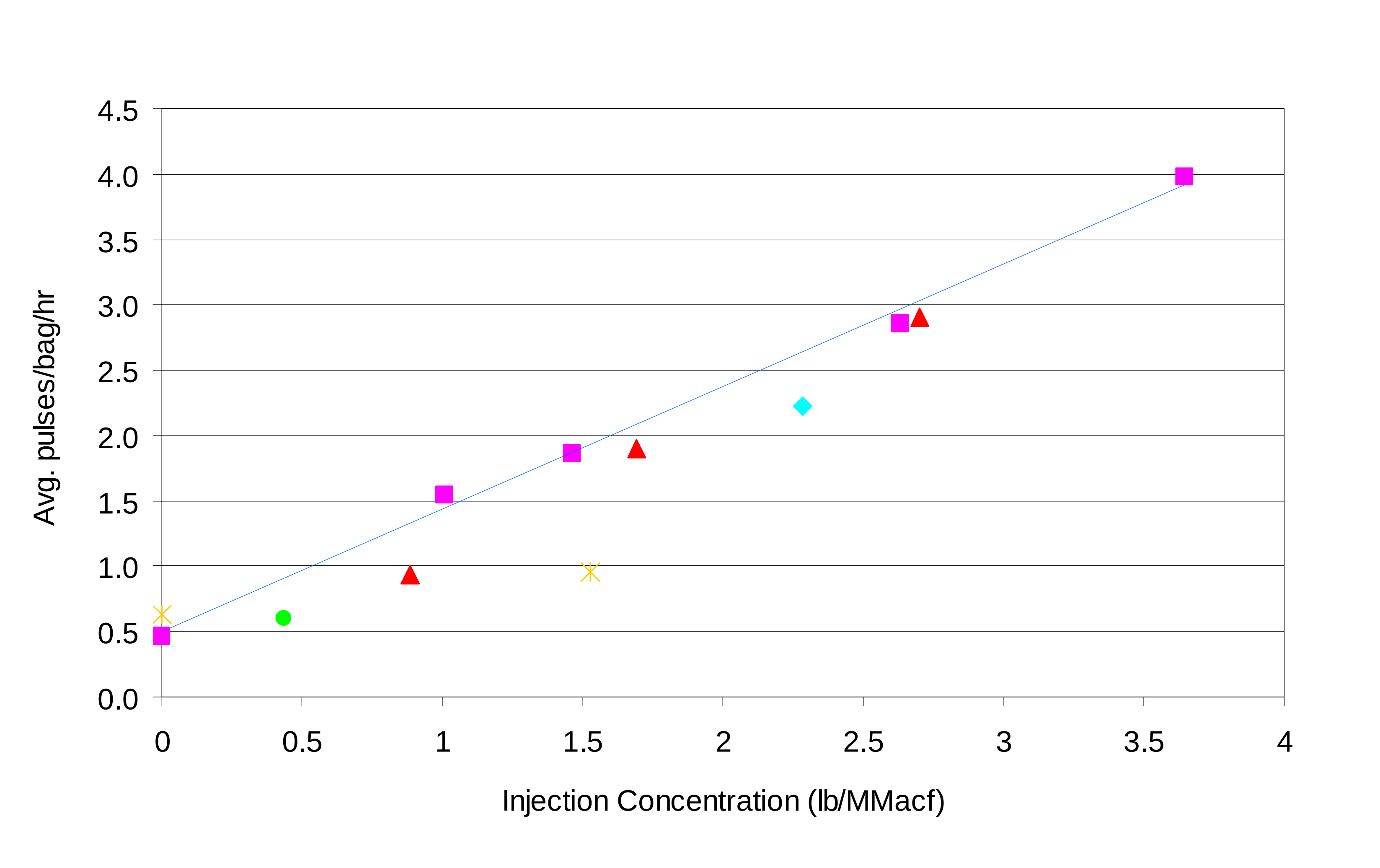
S-CEM Duct Traverse



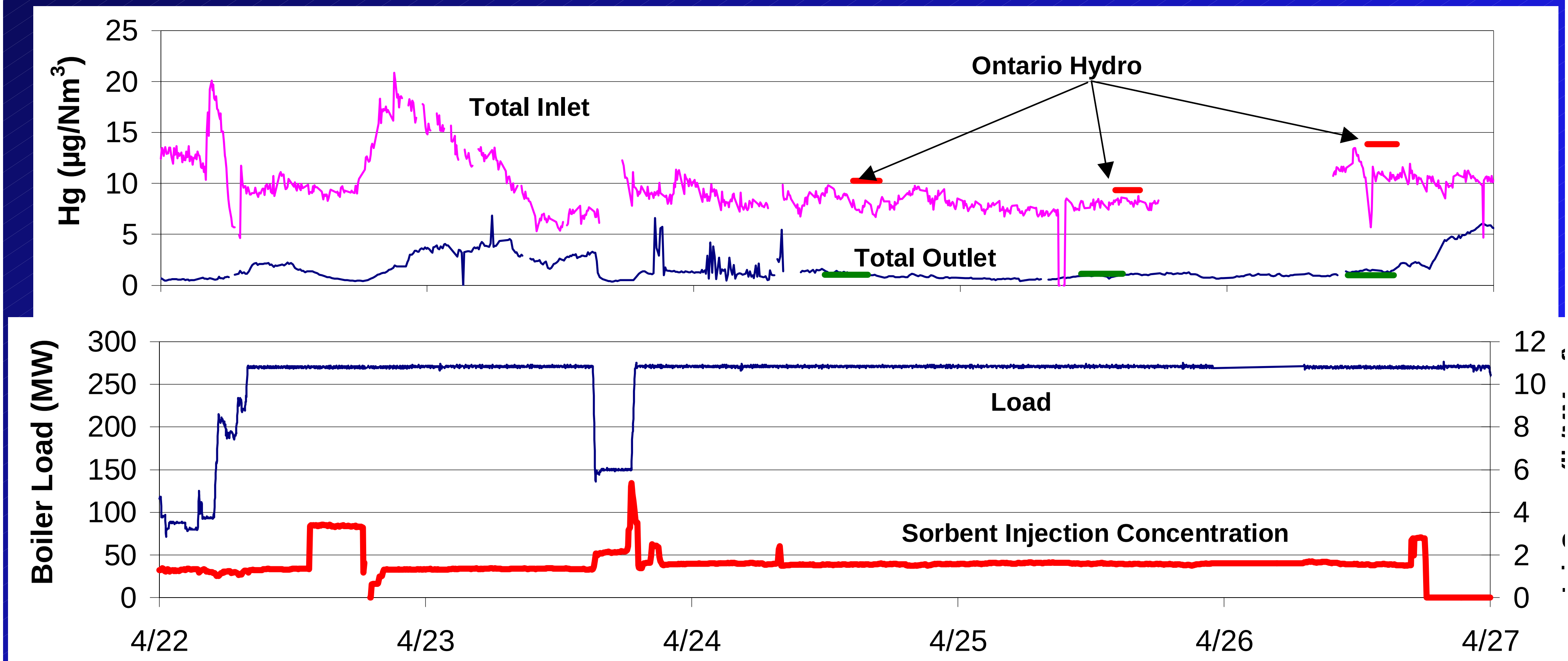
COHPAC Mercury Removal vs. Injection Rate



Impact of PAC Injection on COHPAC Performance



5-Day Continuous Injection



Average Mercury Removal Long-Term Tests Gaston, Ontario Hydro

GASTON ONTARIO HYDRO RESULTS SUMMARY (microgram/dncm)

	PARTICULATE	OXIDIZED	ELEMENTAL	TOTAL
Baseline				
COHPAC Inlet	0.09	9.54	5.97	15.60
COHPAC Outlet	0.01	11.19	3.34	14.54
Removal Efficiency	89.1%	-17.3%	44.1%	6.8%
Long-Term				
COHPAC Inlet	0.23	6.37	4.59	11.19
COHPAC Outlet	0.12	0.91	0.03	1.05
Removal Efficiency	45.6%	85.7%	99.3%	90.6%

Conclusions from Gaston Tests

- Effective mercury control, up to 90% efficiency, was obtained with Darco FGD
- Significant increase in cleaning frequency with carbon injection (COHPAC configuration)
- On average during long-term test, 80-85% mercury removal was obtained
- Actual and theoretical removals were in reasonable agreement
- Tests provide data for design of future COHPAC (TOXECON) baghouses

Future Plans

Run year-long program at Gaston

Document Hg removal under continuous operating conditions

Determine impact of sorbent injection on pressure drop and bag life

WEPCO Pleasant Prairie

- Tests conducted September – November 2001
- PRB coal
- ESP only
- Spray cooling
- SO_3 conditioning system

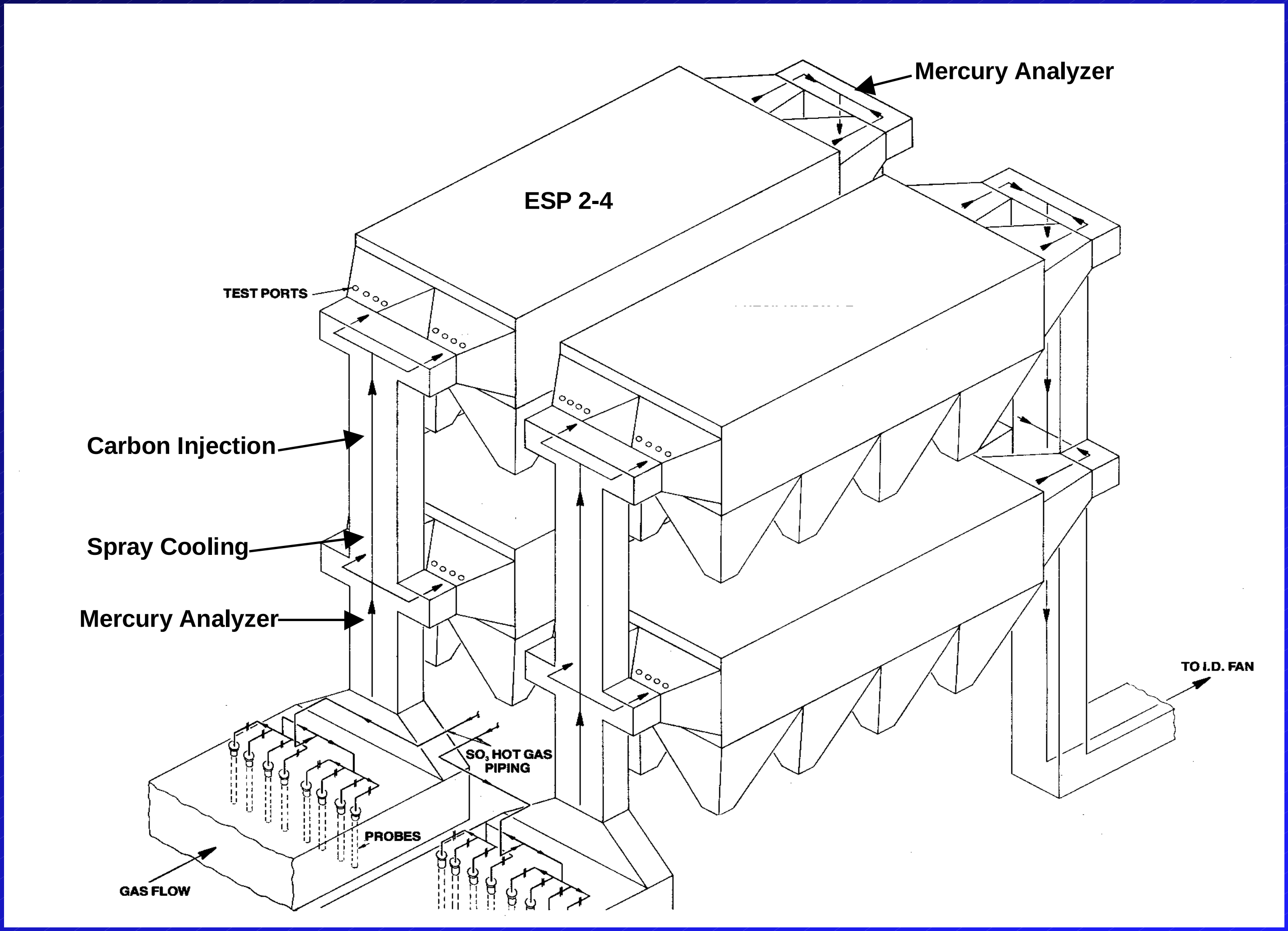
Objective

- Determine the cost and impacts of sorbent injection into the cold side ESP for mercury control
  - Evaluate mercury removal as a function of sorbent injection rate
  - Evaluate impacts including ESP performance and ash marketability

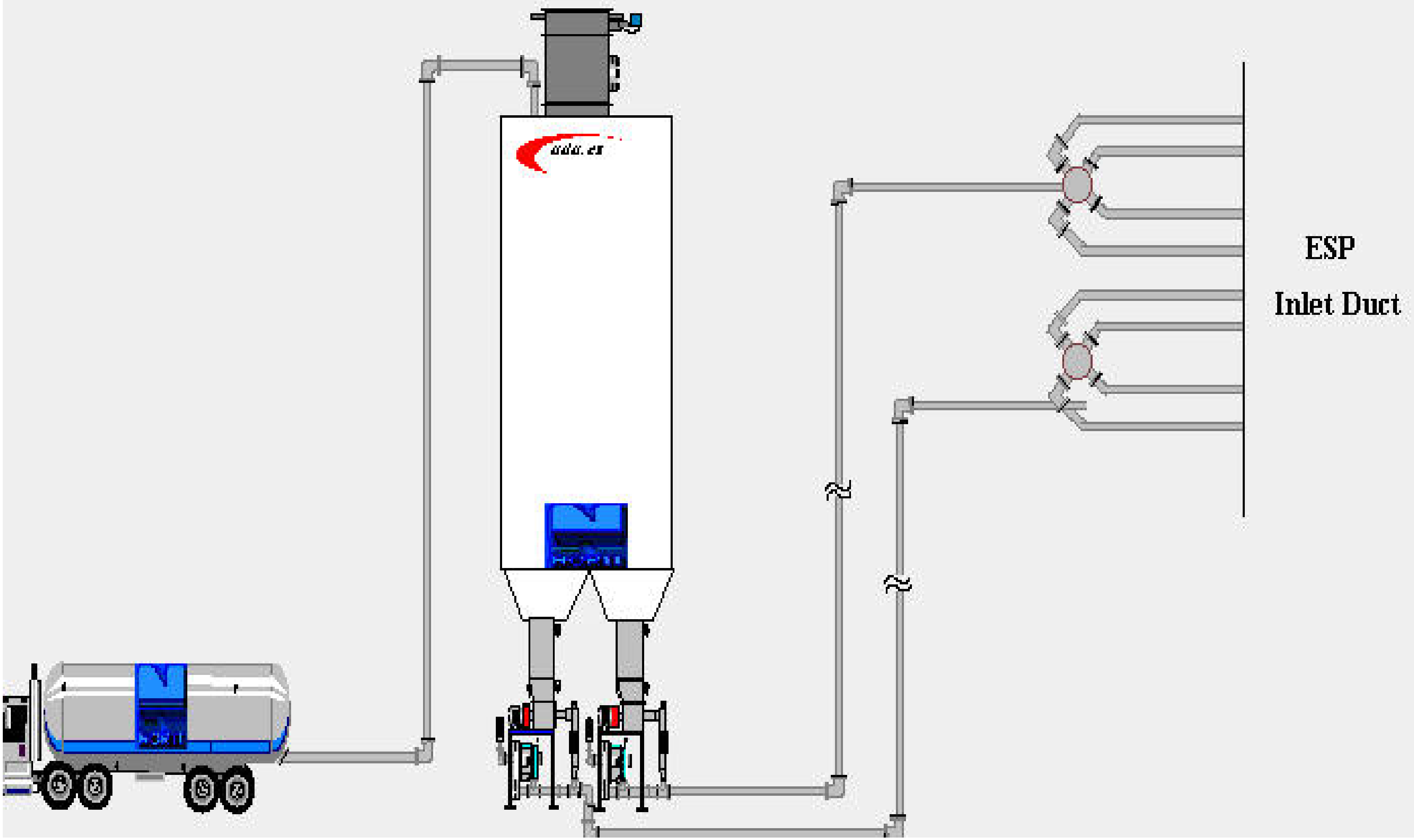
Key Features of PPPP Tests

- Burns coals from the Powder River Basin
- One ESP chamber can be treated in isolation (1/4 of unit ~ 150 MW)
- Baseline mercury removal (1999) showed no removal of mercury by the ash. High percentage of elemental mercury
- Long duct runs provided good residence times for spray cooling and sorbent injection
- Fly ash is currently sold as a valuable commodity. Impacts on ash re-use are important in determining the real costs of mercury control

ESP Configuration, PPPP



Sorbent Injection System



Activated Carbon
Storage and Feed System

Powdered Activated Carbon Delivery System

Powdered Activated Carbon Unloading

Distribution Manifold

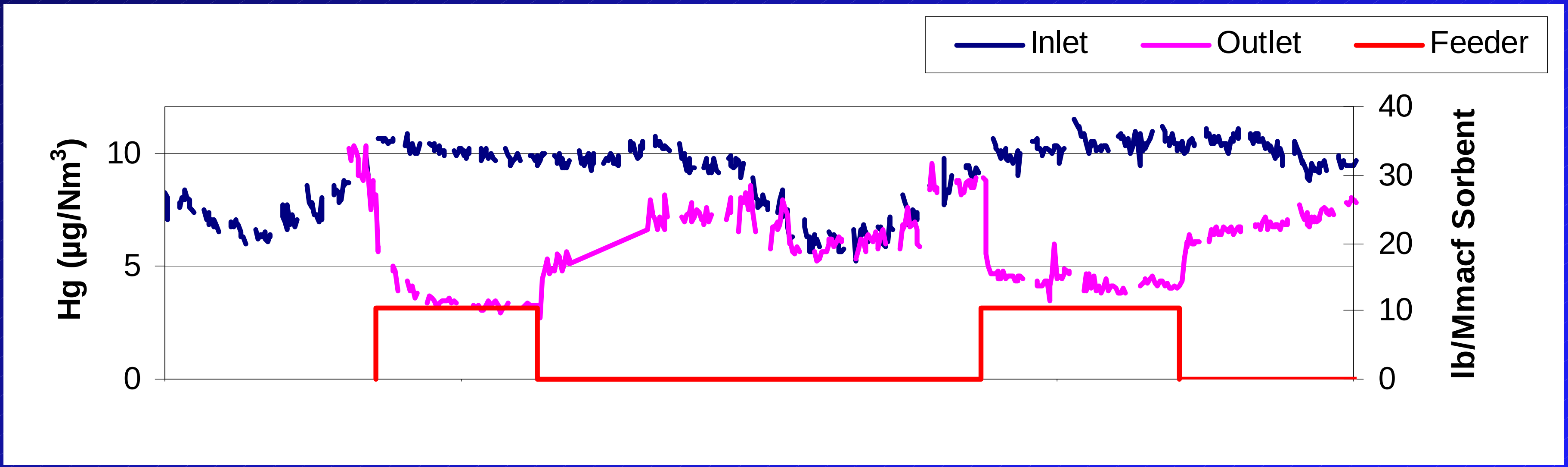
Powdered Activated Carbon Injection System

Week 1 Parametric Tests (FGD)

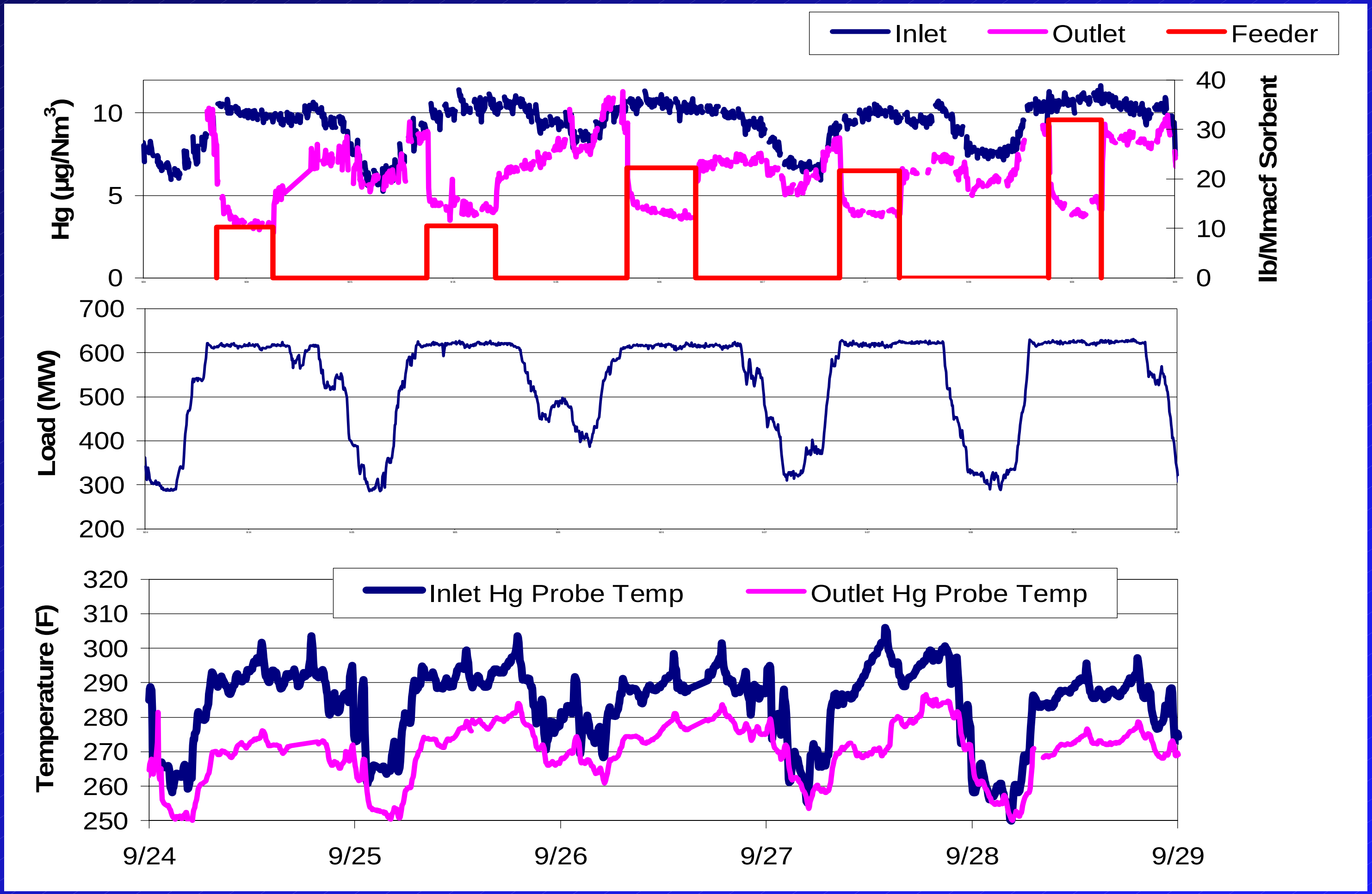
Test ID (Day)	Carbon	Target Injection Rate		Predicted Removal[a] /Actual Removal	Condition/Comments
		lbs/Macf	lbs/hr[b]	%	
P-1: Low Rate (Mon)	FGD	10	360	22/67	SO_3 Off
P-2: Low Rate No SO_3 (Tues)	FGD	10	360	22/60	Standard operating conditions
P-3: Medium Rate (Wed)	FGD	20	720	40/59	Standard operating conditions
P-4: Reduce Temp (Thurs)	FGD	20	720	?/62	Spray cooling lowered to 260 and 270°F
P-5: High Rate (Fri)	FGD	30	1080	51/64	Standard operating conditions

a. Prediction from Meserole in-flight model with 1 sec residence time
b. Based on average flow of 600,000 acfm

SCEM Trend with Injection



Mercury Trends Week 1



Week 2 Parametric Tests (Ground FGD)

Test ID (Day)	Carbon	Target Injection Rate		Predicted Removal[a] /Actual Removal	Condition/Comments
		lbs/Macf	lbs/hr[b]	%	
P-6: Standard Rate (Mon)	Fine[c]	10	360	22/60	Standard operating conditions
P-7: Standard Rate No SO_3 (Tues)	Fine[c]	10	360	22/63	SO_3 Off
P-8: Low Rate (Wed)	Fine[c]	5	180	10/57	Standard operating conditions
P-9: Lower Rate (Thurs)	Fine[c]	2.2	80	?/51	Standard operating conditions
P-10: Even Lower (Fri)	Fine[c]	1.1	40	?/47	Hg levels had not recovered

a. Prediction from Meserole in-flight model with 1 sec residence time(1999)
b. Based on average flow of 600,000 acfm
c. Not able to get fine grind (14 microns), did not expect different performance from FGD

Week 3 Parametric Tests (Ground FGD, FGL, Insul)

Test ID (Day)	Carbon	Target Injection Rate		Predicted Removal [a] /Actual Removal	Condition/Comments
		lbs/Macf	lbs/hr [b]	%	
P-10a: Rerun P-10 (Mon)	Fine [c]	1.1	40	?/36	Standard operating conditions
P-11: Standard Rate (Tues)	FGL	10	360	22/54	Standard operating conditions
P-12: Low Rate (Wed)	FGL	5	180	10/49	Standard operating conditions
P-13: Lowest Rate (Thurs)	Insul	0.5	20	?/47	Standard Conditions Fill in performance curves
P-14: Low Rate (Thurs)	Insul	1.0	36	?/47	Standard Conditions Fill in performance curves
P-15: Low Rate (Thurs)	Insul	2.0	72	?/47	Standard Conditions Fill in performance curves
P-16: Low rate (Thurs)	Insul	5.0	180	?/47	Standard Conditions Fill in performance curves
P17: Standard Rate (Fri)	Insul	10	360	?/60	Compare to other carbons

a. Prediction from Meserole in-flight model with 1 sec residence time(1999)
b. Based on average flow of 600,000 acfm
c. Not able to get fine grind (14 microns), did not expect different performance from FGD

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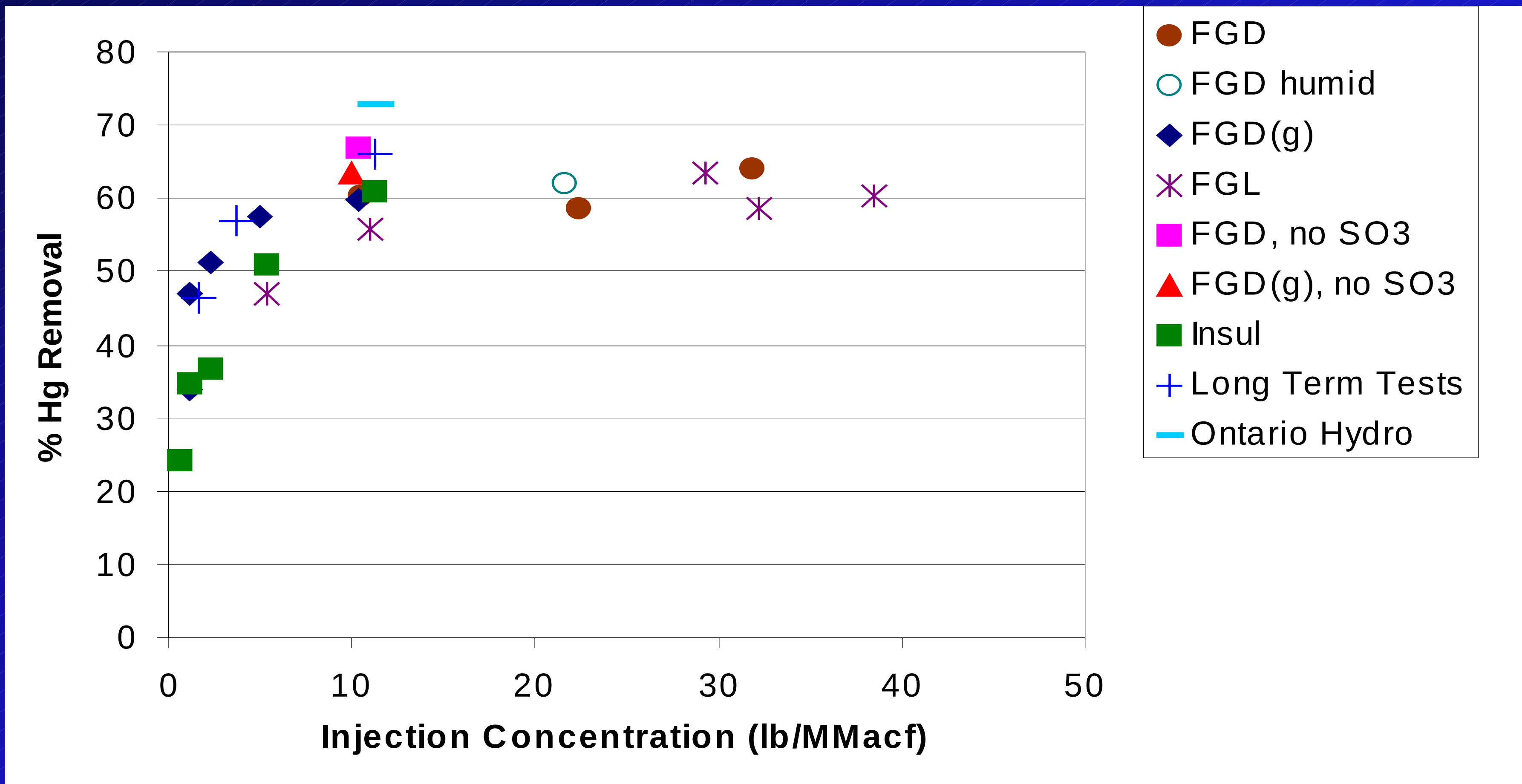
Carbon Injection Performance on a PRB Coal with an ESP



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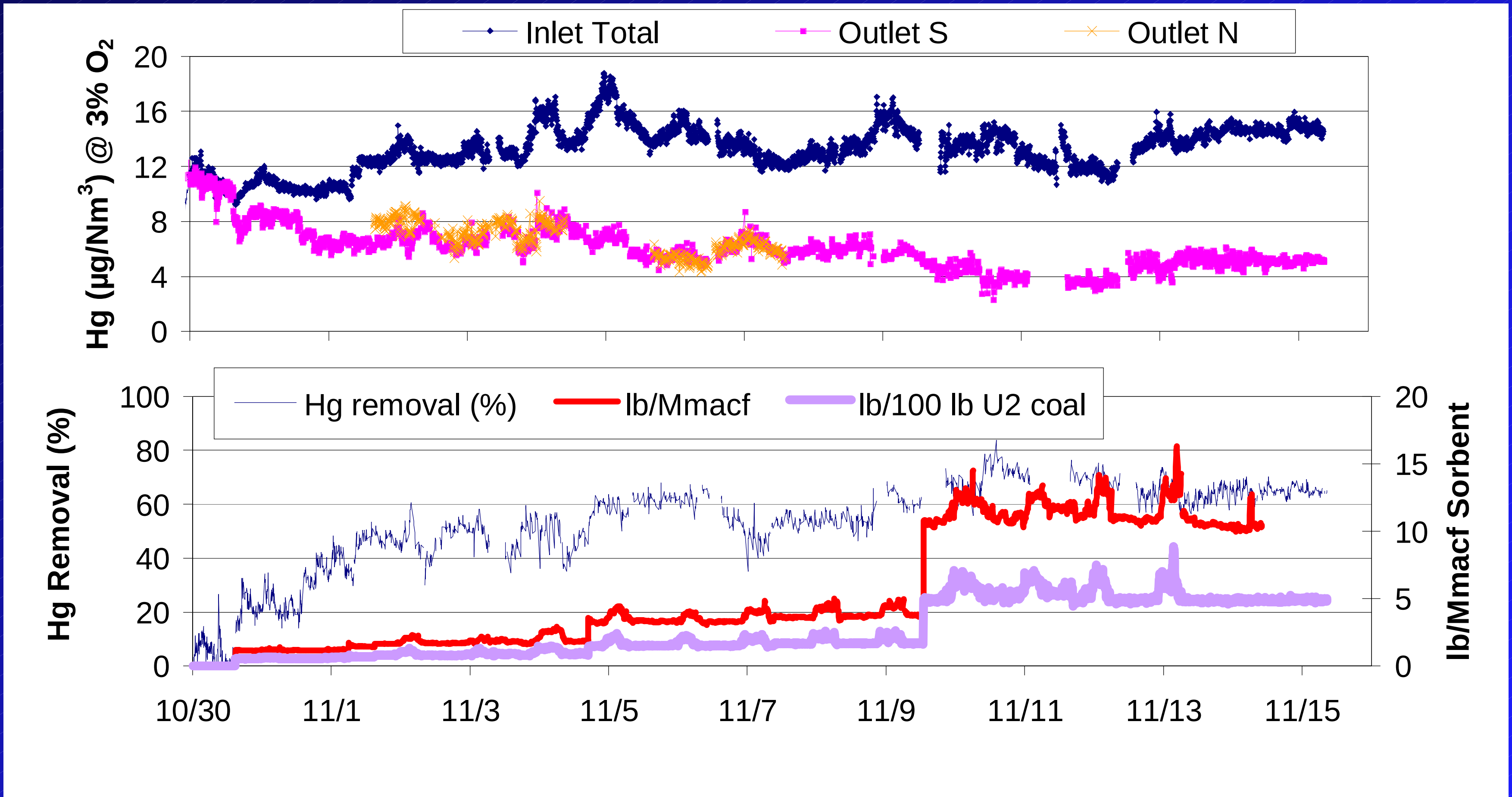
Parametric Test Conclusions

- Higher than expected removal observed at very low injection rates
- Hg removal improves rapidly with injection rates up to nominally 5 lbs/Mmacf
- Increase in performance minimal above 5 lbs/Mmacf
- No significant impact of SO_3 injection on Hg removal
- No improvement with spray cooling of 40 – 50ºF
- No significant difference between carbons
- Smaller of sorbent did not improve performance

Long-Term Test Plan (5 days each)

- All tests conducted with Norit Americas Darco FGD
- Very low rate of 1 lb/MMacf
  - Minimize impact on ash
  - What is removal efficiency at very low rate?
- Low rate of 3 lbs/Mmacf
  - Logarithmic “middle” point
  - Will removal efficiency increase with time?
- Highest removal at 10 lbs/MMacf
  - Ontario Hydro Tests
  - Impact on ESP

Long-Term Trend Data



Speciated Mercury Measured by S-CEM

Species (microg/dncm)	1 lb/Mmacf Inlet	1 lb/Mmacf Outlet	3 lb/Mmacf Inlet	3 lb/Mmacf Outlet	10 lb/Mmacf Inlet	10 lb/Mmacf Outlet
Particulate	NA	NA	NA	NA	NA	NA
Elemental	10.7	4.9	11.7	4.5	11.0	3.2
Oxidized	1.3	1.9	2.2	1.5	2.6	1.3
Total	12.0	6.8	13.9	6.0	13.6	4.5
% Oxidized	11	28	16	25	19	28

Note: Total and elemental mercury measured directly, oxidized mercury calculated from the difference.

Speciated Mercury Measured by Ontario Hydro Method (10 lbs/MMacf)

PPPP ONTARIO HYDRO RESULTS SUMMARY (microgram/dncm)

	PARTICULATE	ELEMENTAL	OXIDIZED	TOTAL
Baseline				
ESP Inlet	1.97	12.22	2.51	16.71
ESP Outlet	0.01	9.80	6.01	15.82
Removal Efficiency	99.5%	19.8%	-139.3	5.3%
Long-Term				
ESP Inlet	0.98	14.73	1.73	17.44
ESP Outlet	0.00	4.27	0.44	4.71
Removal Efficiency	100.0%	71.0%	74.5%	73.0%

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Comparison of OH and S-CEM*, Long-Term Tests (10 lbs/MMacf)

Run Number	Run 1		Run 2		Run 3		Average	
Date	11/12/2001		11/13/2001		11/13/2001			
	S-CEM*	OH	S-CEM*	OH	S-CEM*	OH	S-CEM*	OH
Inlet (micrograms/dncm)	13.5	15	13.7	18.3	14.3	19.1	13.8	17.4
Outlet (micrograms/dncm)	4.8	4.0	5.1	5.0	5.4	4.7	5.1	4.7
Removal Efficiency (%)	64.4%	73.4%	62.8%	72.8%	64.0%	75.3%	63.7%	72.9%

* S-CEM measures only gas phase mercury, average calculated over same time as OH tests

Long-Term Test Conclusions

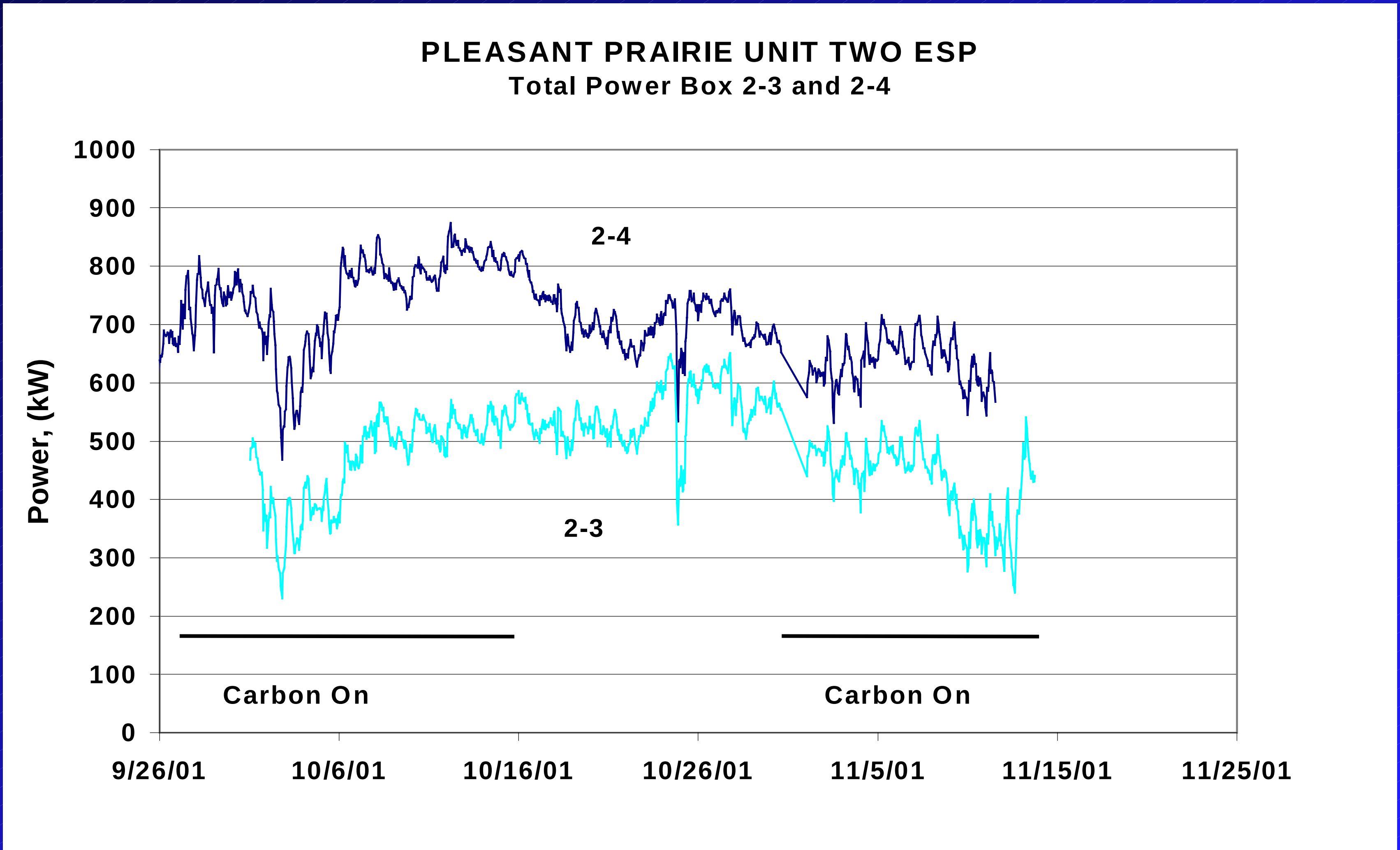
- Hg removal efficiency of 40 - 50% obtained at 1lb/Mmacf
- Hg removal efficiency of 50 - 60% obtained at 3 lb/Mmacf
- Hg removal efficiency of 60 - 70% obtained at 10 lb/Mmacf
- PAC injection reduced both elemental and oxidized mercury concentrations
- Fly ash could not be used for concrete with any trace of PAC present
- No detrimental impact on ESP performance
- On a PRB ash, if the gas temperature is below 300 ºF, it appears that additional cooling does not improve capture of mercury

Balance of Plant

ESP Test Results

- No apparent detrimental impact on performance during two week test
  - Carbon levels of 2 to 5% not high enough
  - Our experience, Carbon levels in the 20 to 30% range to affect performance
- Power levels appear to increase
- No measurable increase in opacity or mass emissions

Comparison of Power Levels in ESPs with (2-4) and without (2-3) Carbon Injection



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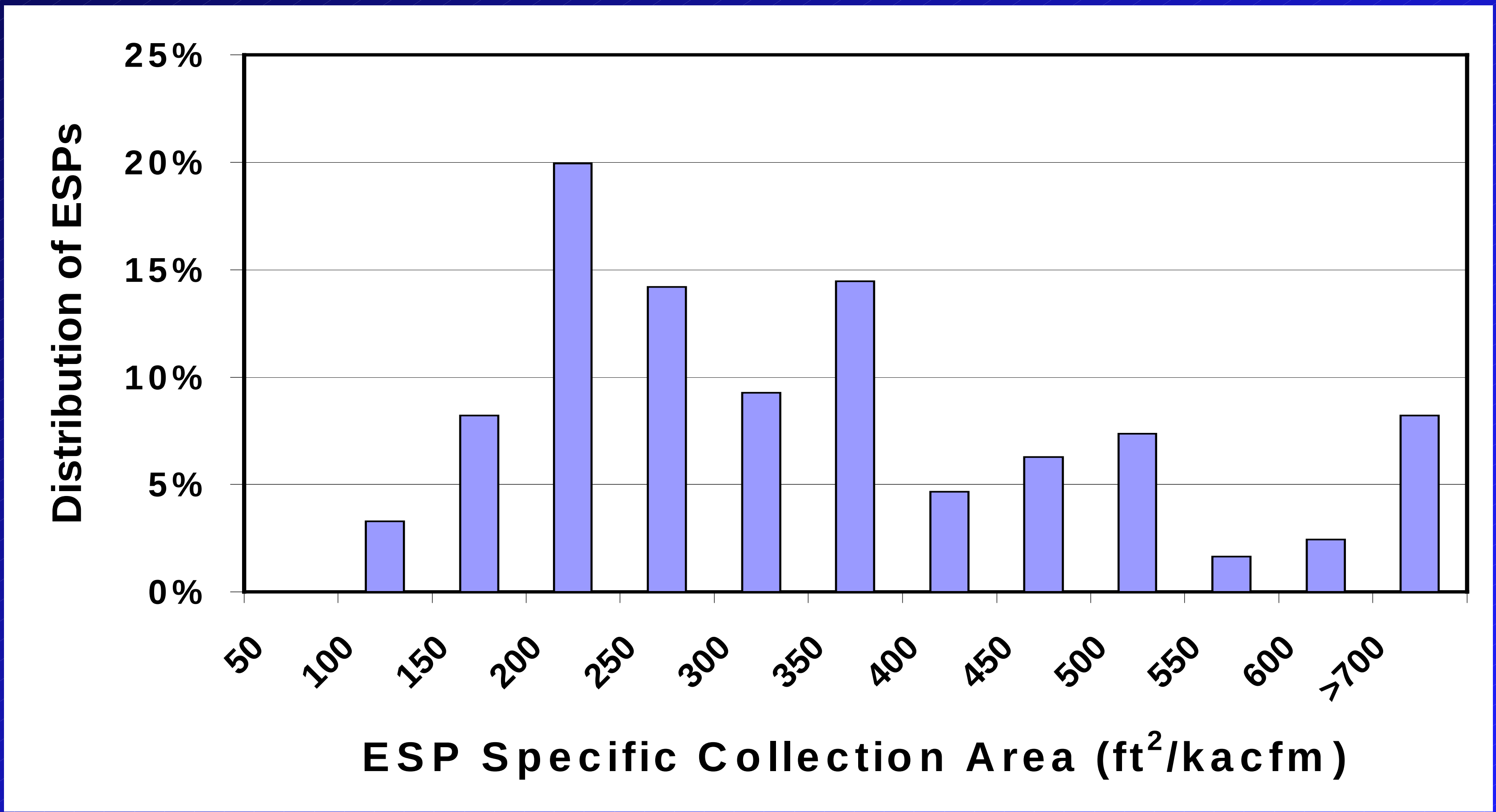
ESP Test Results (cont.)

- Carbon penetrated ESP (carryover)
  - Hoppers samples
  - Hg sampling issues
- Took a month of operation to clear ESP of carbon
- P4's ESP (SCA) is not representative of the utility population, 468 SCA vs. 200 SCA
- Long-term testing needed to determined impact on ESP performance

ESP SCA Distribution



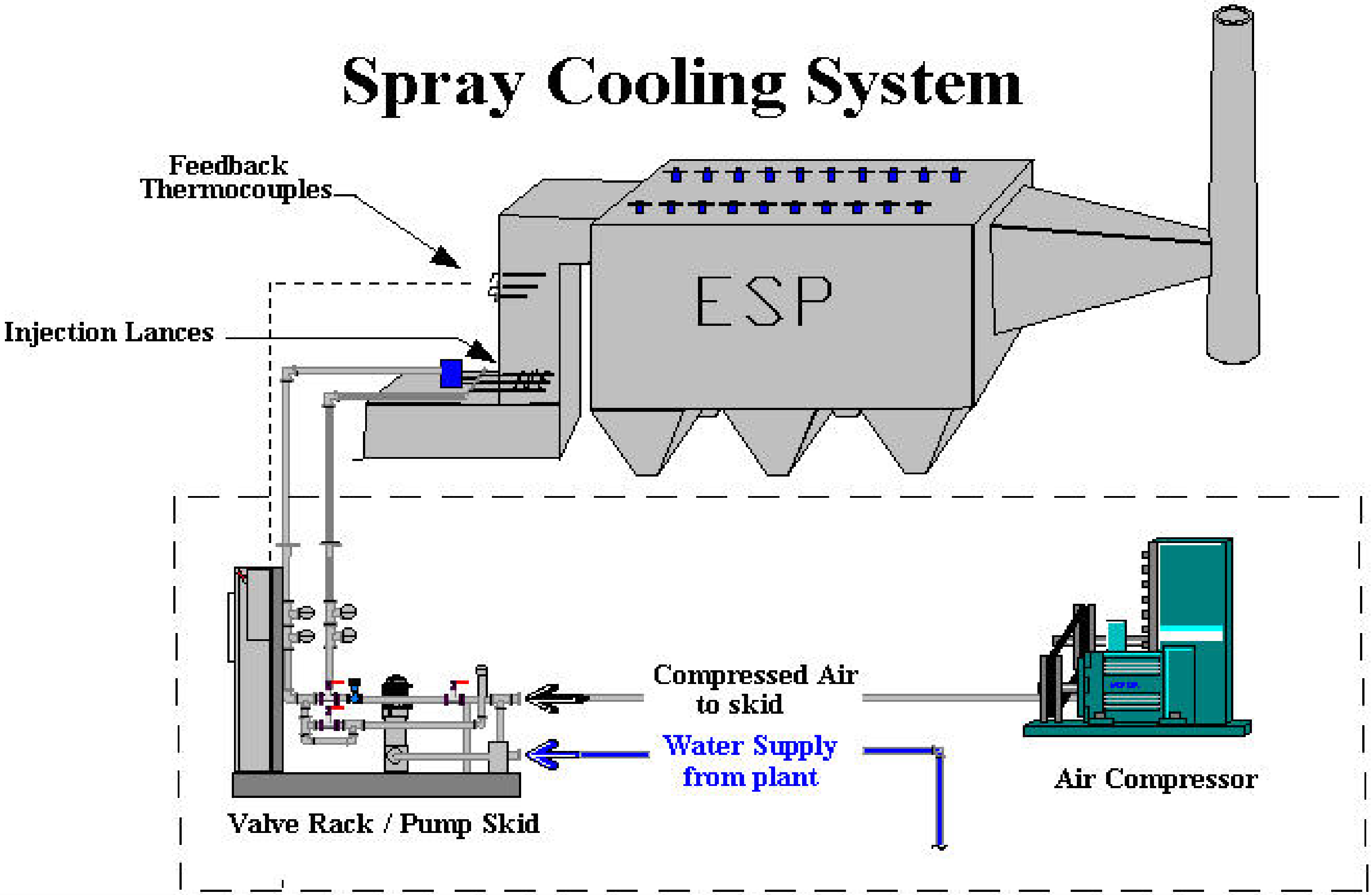
Impact of ESP SCA on the Performance of Hg Control Systems

- Size limits how much sorbent can be added before particulate emissions increase.
- The smaller ESPs will have higher velocities and will be more subject to reentrainment of the low-resistivity carbon particles
- The residence time in the ESP is directly proportional to the SCA. Therefore, the larger ESPs will have greater opportunity for interaction between the sorbent and the gas phase mercury

Spray Cooling System

- Supplied by EnviroCare International
- Booster pump/valve rack skid
- Two cooling zones
- Dedicated compressor
- Spray lances with dual-fluid atomizers
- Fast-response feedback thermocouples
- PLC controls

Spray Cooling System



Spray Cooling Risks

- Primary risks
  - Corrosion
  - Duct Deposition
- Safe guards
  - Removal of internal ductwork brace
  - Fast Response thermocouples
  - In-duct camera
  - Advance control system

Spray Cooling Test

Step 1: Cooled temperatures 10 – 25ºF to 260ºF

No change in mercury removal
No sign of deposition

Step 2: Cooled temperatures 20 – 35ºF to 250ºF

No change in mercury removal

Within 45 minutes deposition observed on probes approximately 40 ft downstream of spray lances

Water injection rate

~ 13 gpm for 260ºF
~ 18 gpm for 250ºF

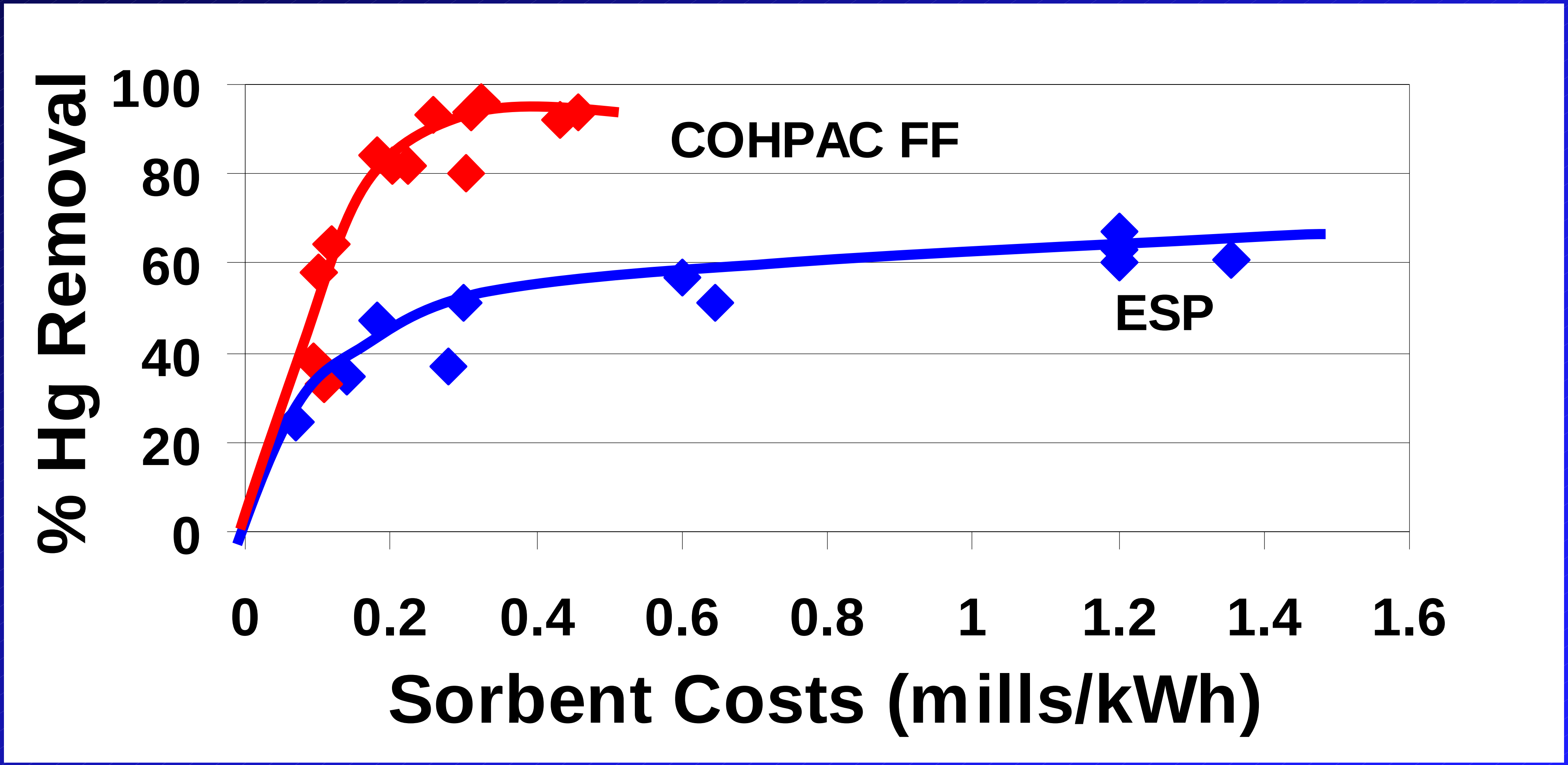
Spray Cooling Results

- Cooling flue gas to 260°F and 250°F had no impact on Hg removal at P4
- Duct deposition very sensitive to water injection rate
- Cooling flue gas improved ESP performance
  - Reduced flue gas volume - decreased gas velocity
  - Decreased resistivity - increased power levels

Design Consideration

- Demonstration system (1/4 unit) largest built to date
- Configuration/redundancy needed for whole unit
- Specific material feed design for each sorbent material - size distribution & bulk density
- Pneumatic transport lines - long term wear issues
- Closed loop Controls - Control signal
  - Flue gas, fuel or steam flow?

Comparison of Sorbent Costs for a Fabric Filter and an ESP



Next Steps

- Gain additional experience with sorbent injection
  - Additional test sites with different fuels and configurations
  - Longer-term tests
- Investigate solutions to carbon-in-ash issues
- Accelerate development of CEMs to commercial systems
- Address long-term supply of activated carbon

Increased Operating Experience

- **Short-term testing at additional sites**
  - PG&E Brayton Point (Bituminous coal, large ESP) — Summer 2002
  - PG&E Salem Harbor (Bituminous coal, SNCR, large ESP) — Fall 2002
  - * TBD (PRB coal, small ESP) — Winter 2003
  - * Southern Company (Bituminous coal, small ESP) — Summer 2003
- **Long-term testing**
  - *Alabama Power (Bituminous coal, COHPAC FF) — 8/2002-2003
  - *CCPI Program (PRB Coal, COHPAC FF) — 2004-2006
  - *CCPI Program (Bituminous Coal, COHPAC FF) — 2004-2006

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Carbon-in-Ash Issues

- Research on use of ash with activated carbon
  - EPRI
  - Wisconsin Electric
  - ADA-ES
  - Brown University
  - DOE
  - Norit

Maturation of Mercury CEMs

- Current systems require full-time operation
- A few “commercial” Hg detectors are available
- Detectors need to be integrated with key system components for use at power plants
  - Remove particles without contacting the gas
  - Convert all mercury species to elemental mercury
  - Calibration
  - Data processing
- ADA-ES planning on developing complete Hg CEM system as part of CCPI program

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Carbon Supply

- Current production of powdered activated carbon (PAC) is 250,000 tons/yr
- Power industry could require as much as 2,000,000 tons/yr
- New production facilities could cost $100M each
- Integrating carbon suppliers into demonstration programs to make them comfortable with this developing market